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# DATA TRANSMISSION METHOD AND DATA TRANSMISSION SYSTEM

## FIELD OF THE INVENTION

The invention relates to a data transmission method for enclosed environments, such as a mine, the data transmission method being used in a data transmission system comprising one or more terminals and a network comprising at least one base station, a monitoring station and a backbone network, the data transmission system having a radio connection between the terminal and the base station and a bi-directional connection from the monitoring station to one or more working machines via the terminals, each of which is coupled to a working machine.

The invention further relates to a data transmission system to be used in enclosed environments, such as a mine, the data transmission system comprising one or more terminals and a network comprising at least one base station, a monitoring station and a backbone network, the data transmission system having a radio connection between the base station and the terminal and a bi-directional connection from the monitoring station to one or more terminals, each of which is coupled to a working machine.

## BACKGROUND OF THE INVENTION

Automatically operating and/or remotely controlled machines, controlled and monitored either from above ground or from underground monitoring stations are associated with large-scale mining automation. Automation enables higher production, lower production costs and improved working environment for the staff. A communication network for transmitting multimedia information between production sites and monitoring stations is needed for teleoperating large machines and for other communication.

Present prior art mining data transmission systems are mainly analog. Their performance, security and capacity are, however, insufficient for extensive automation applications. In a typical system, video image, voice and data are transmitted analogously in channels having relatively slow transmission rates. In addition, the signal of each information source is modulated to a dedicated carrier and the signals are distributed to the mine along a coaxial cable operating as the backbone network and having a radio connection to the machines. The radio connection is implemented either by antennae or the backbone network is partly or entirely based on leaky cables. Such a solution is disclosed in Canadian Patent Application No. 2,057,544, *Communication*

*system*, which is incorporated herein by reference. A backbone network is typically several kilometres long, and the signals to be transmitted have to be amplified at given intervals to compensate for cable attenuation. Since amplifiers and other devices used for signal transmission are in practice slightly non-linear, signals form cross correlation results limiting connection quality. Particularly for this reason, numerous measurements and signal level tunings are needed when a backbone network is installed. This again causes network installation to be expensive and difficult to modify.

Patent publication US 5,697,067, incorporated herein by reference, discloses a communication system particularly for mines. The communication system of the publication uses radiating transmission lines, the aim being to reduce the intermodulation generated therein. The communication system according to the publication is also able to transmit video images. Patent publication GB 2 288 300, incorporated herein by reference, discloses an image transmission system in which image coding operates as an encryption code simultaneously reducing the bandwidth required in image transmission. However, neither communication system provides real-time data transmission for teleoperation.

Digital data transmission systems provide better connections than analog systems. A typical problem in these systems is, however, that data transmission is not real-time. In systems based on e.g. LAN architecture, the LAN protocols are unable to ensure that the data to be transmitted is transmitted from the sender to the receiver always equally rapidly, or even that the data is transmitted at least within a predetermined period of time. The data transmission delay of a typical prior art digital data transmission system is too high and varying for real-time teleoperation. Consequently, the use of digital systems in mines in particular is limited to non-real-time applications, i.e. applications with non-critical response times.

## BRIEF DESCRIPTION OF THE INVENTION

It is an object of the invention to provide a method and an equipment complying with the method to solve the above problems. The solution of the invention enables the implementation of real-time transmission of multimedia information from a mining shaft to a monitoring station.

This is achieved by a method of the type presented in the introduction, characterized in that data between the monitoring station and the terminal

is transmitted digitally, and one or more working machines are controlled from the monitoring station by teleoperation substantially in real time by a deterministic data transmission protocol in which the data transmission delay is within predetermined limits.

The data transmission system of the invention, in turn, is characterized in that the data transmission system is arranged to transmit data digitally between the monitoring station and the terminal, and the data transmission system comprises a deterministic data transmission protocol by which one or more working machines can be controlled by teleoperation substantially in real time and in which the data transmission delay is within predetermined limits.

The method and system of the invention provide a plurality of advantages. User data is transmitted in the system at a predetermined delay irrespective of system load. Interference is lower, the coverage areas of the base stations are larger, and the system is easier to install and modify than prior art solutions. Furthermore, video signal quality is better and the number of connections is higher than with known solutions. In addition, the security of a digital system is superior to that of an analog system. Teleoperating requires a real time system, a feature that prior art digital and teleoperative multimedia systems having a plurality of simultaneous users are unable to provide.

## BRIEF DESCRIPTION OF THE DRAWINGS

In the following the invention will be described in greater detail in association with preferred embodiments with reference to the accompanying drawings, in which

Figure 1 shows a data transmission system;

Figure 2 shows a packet used in data transmission;

Figure 3 shows a working machine connected to a data transmission system;

Figure 4 shows a monitoring station, and

Figure 5 shows a protocol stack.

## DETAILED DESCRIPTION OF THE INVENTION

The solution of the invention is particularly suitable for use in a mine, but is not, however, restricted thereto. Other application areas for the invention include tunnels, buildings, open-cast mines and areas involving critical security aspects (nuclear plants, mine clearing). The basic idea of the invention is to provide transparent point-to-point type data connects between

terminals and monitoring stations. The monitoring stations and terminals provide an interface for connecting peripheral devices, such as remote control desks, computers, cameras and other devices.

The digital broadband data transmission system of the invention is well suited to the teleoperation and monitoring of heavy mining machines. Let us study the solution of the invention by means of the example in Figure 1. The system comprises in a network 20 at lest one monitoring station 10 to 12, a network connection 13, switch means 14, a main cable 15, another network connection 16 and base stations 17. The system further comprises terminals 18, coupled to working machines 19 to enable control and monitoring. The network connection 13, the switch means 14 and the main cable 15 constitute the backbone network. The minimum configuration of the backbone network of the invention comprises only a main cable 15 between a monitoring station 10 to 12 and a base station 17; a radio connection can be used instead of the main cable. Consequently the network 20 only comprises a monitoring station 10 to 12, the backbone network (the main cable 15 or a radio connection) and a base station 17. Data transmission is digital between the monitoring station 10 to 12 and the working machine 19 in the data transmission system of the invention. The data transmission system further comprises a deterministic data transmission protocol, by means of which one or more working machines 19 can be controlled from the monitoring station 10 to 12 by teleoperation substantially in real time, since by means of the data transmission protocol, the data transmission delay remains within predetermined limits irrespective of the load. Real time refers to operation taking place approximately in sync with the process. In the solution of the invention, the highest data transmission delay is preferably less than 10 ms.

The backbone network, composed of the cables 13, 15 and 16 and the switches 14 serves as the backbone of the network 20, which operates preferably on a multicasting principle, whereby transmitted messages are forwarded to more than one units connected to the network. In this event, a message sent from e.g. the monitoring station 10 first propagates to the switch 14, which sends it to the monitoring stations 11 and 12, and further to the main cable 15, from where the message propagates to all units 14, 17, 18 and 19. In stead of transmitting the messages to all units, the number of message receivers can also be limited. In this case the monitoring station 12 can be e.g. in a bi-directional connection to only the right-hand terminals 18 and working

machines 19. In this case the monitoring station 12 and the right-hand terminals 18 and working machines 19 do not preferably see the rest of the system. Other devices (e.g. terminals, sensors etc.), not visible in the system, but using it, can be connected to the backbone network by similarly restricting multicasting connections.

The network 20 is preferably an ATM network (Asynchronous Transfer Mode) or the like. The ATM network typically enables a data transmission rate of 155 Mbps. One connection between a working machine 19 and a monitoring station 10 to 12 requires a data transmission rate of e.g. 1 Mbps, and consequently an ATM backbone network enables the simultaneous monitoring and control of at least several dozens of working machines 19 from each monitoring station 10 to 12.

In a preferred embodiment of the invention, the ATM backbone network operates on the multicasting principle by the ATM routing switches 14 operating independently without separate control. In this event the switches 14 direct a received message to all units of the data transmission system. This deviates somewhat from the conventional operation of ATM network switches. The ATM switches are programmed such that packets coming from one port are sent as such, without changing the address and data fields, to all other ports. The multicasting principle simplifies the system since it dispenses with the extremely heavy signalling which is currently incompletely determined in e.g. the ATM network.

Instead of operating independently, the ATM backbone network can operate on the multicasting principle by the ATM switches 14 being centrally controllable. The switches 14 are preferably controlled by signalling from the monitoring stations 10 to 12. In this case the switches 14 direct the messages to different units as desired. This allows unnecessary data transmission to be reduced. For example, the monitoring station 10 can be first in a multicasting connection only to the right-hand units of Figure 1, and later to only the lower units in Figure 1. In this event the arrangement is invisible to the rest of the system, and the other parts of the system are unable to see this arrangement. The switches 14 are preferably FSR switches (Frame Synchronous Ring). A prior art FSR switch is based on ring topology and is simple and efficient. An FSR switch is suitable for broadband switch applications. FSR switches that are suitable for the ATM interface also enable e.g. the use of optical fibre at the rates of 155 Mbps (SDH/STM-1) and 100 Mbps (TAXI) and the use of a

metal conductor at the rates of 34 Mbps (PDH/E3) and 2 Mbps (PDH/E1).

The data transmission system of the invention establishes a connection between a terminal and a base station preferably by wireless spread spectrum signalling, although the connection can also be established without the spread spectrum technique. In spread spectrum technique, a narrowband user data signal is modulated to a broader band than that required by the data signal. In prior art solutions where the signal of each transmitter is modulated to its own carrier, the terminal amplifier of the monitoring station 10 to 12 and possible intermediate repeaters in the network 20 have to process a multi-carrier signal. This causes an intermodulation problem. The power of each carrier has to be kept low to reduce intermodulation, resulting in short signal range. In a mine, radio signal scattering and reflection causes multipath propagation and fading, leading to major problems in prior art solutions. In the inventive solution the intermodulation problem is eliminated since video, data and audio signals are digitized and multiplexed to a common bit stream as early as at the terminal, whereby preferably only one carrier is required for each terminal. Since the intermodulation problem is eliminated, higher transmission powers can be used, resulting in longer signal ranges. Since the range is longer, cabling and antennae do no longer have to be installed in the furthermost corners of production areas. The spread spectrum technique again causes the effect of multipath propagation to decrease. In addition, data is transmitted digitally in base band in the network, whereby no intermodulation is created.

The data transmission system is arranged to perform data transmission in broadband, the data transmission system comprising a plurality of multimedia channels so that the system in principle enables an almost unlimited number of connections between a mining shaft/terminal and a ground level/monitoring station. In addition to voice and speech signals, the broadband feature thus enables the simultaneous transmission and reception of video, data and control signals both in the mining shaft and above ground. The data transmission system thus transmits one or more of the following information types substantially simultaneously: image, voice, data. Image information can be used to control the performance of a working machine 19, to control a working machine 19 from one tunnel to another to the working site, etc. Voice information can contain e.g. motor sounds, allowing the monitoring station 10 to 12 to hear if the engine is operating correctly etc. Voice information also

includes human speech from the monitoring station 10 to 12 to the mine or from the mine to the monitoring station 10 to 12. The data and control signals are used e.g. to monitor the condition of working machines by sensors disposed in the working machines and to control the working machines 19.

The data transmission system transmits image, voice and data preferably as packets, which are preferably ATM cells or the like. The packets are transmitted unchanged across the radio interface. The base station 17 and the terminal 18 can have radio communication with one another in accordance with the FDMA (Frequency Division Multiple Access), TDMA (Time Division Multiple Access), SDMA (Space Division Multiple Access) or CDMA (Code Division Multiple Access) methods. The CSMA/CD method (Carrier Sense Multiple Access with Collision Detection) can also be used, but one has to ensure that the operating system is sufficiently rapid for real-time operation even in data collision. The system uses e.g. 1 to 50 MHz bandwidths. In FDMA, users are distinguished from each other on the basis of the frequency band, in TDMA users transmit in different timeslots, in SDMA signals are directed to the receiver, and in CDMA users are distinguished from each other by means of a spreading code.

Each terminal has a fixed data transmission band which the data transmission system allocates to image, voice and data. With a plurality of data and control signals, less data transmission capacity is left for image and voice. In the inventive solution, image and voice are compressed digitally in the data transmission system to enable more efficient data transmission. By compression the bandwidth required for transmitting a video signal can be dropped even 50 times smaller as compared with an uncompressed video signal, without impairing image quality. Data and control signals are not compressed in the inventive solution. The solution of the invention allows any prior art image compression method. In the data transmission system image is preferably compressed dynamically, that is, if the data transmission need exceeds the available capacity, a video signal is compressed more and more until the data transmission need required by the video signal corresponds to the available amount. This provides a data transmission band that is sufficient in all situations and ensures transmission by a deterministic delay for high-priority data, such as control data. Transmission capacity is not unnecessarily reserved for any information, although the amount of information to be transferred varies. The characteristics, i.e. information contents, of an image are

consequently reduced in compression, if need be, to an extent that the information therein always fits into the remaining data transmission band. This ensures an optimal image quality.

In the inventive solution, image compression is assisted e.g. by digital adapted median filtering of a video image, in which a reference value is generated for the pixel block to be processed. The value of each pixel of a pixel block is compared with the reference value, and if the pixel value deviates from the reference value by more than a threshold value, the pixel value is replaced by the reference value. In dynamic compression the magnitude of the threshold value can be preferably adapted according to the available data transmission capacity/bandwidth.

In packet-mode transmission a fixed bandwidth means that each terminal transmits in a time unit a fixed number of packets, into which image, voice and data have to be placed. This way the information contents of an image are reduced, if needed, during compression to a degree that its information always fits into the space left in each packet by data and voice. The data transmission protocol used in the inventive solution is also optimized for data transmission across the radio/backbone network interface. In this event packet-mode presentation of the data remains unchanged in the entire data transmission system.

A packet, shown in Figure 2, resembles an ATM cell and comprises an MT/ID part 21, which is a machine identifier, and a data part 22. The entire packet comprises 48 bytes. Data is divided into N fields, each comprising a header 23 and a data part 24. Each header comprises a pipe number 25 and data length in bytes 26. One byte typically comprises 8 bits. A packet comprises data of 7 different pipes and general control data of the entire system, transferred in pipe 0.

The data transmission system establishes logical connections between units by means of a graphic user interface. A logical connection means that a physical connection, e.g. a conductor, changes with time, but the connection, or the actual data transmission itself does not change nor is disturbed by changes in the physical connection. Typical graphic user interfaces include Windows and X-windows. A graphic user interface provides a user distinct information on the units connected to the network, disturbances in communication, hardware failures and enables flexible establishment of logical connections between the units.

Remote control desks, computers, cameras and other devices are connected to the inventive data transmission system e.g. by the following interfaces 13 and 16: RS-232, RS-485, Profibus and Ethernet LAN.

Figure 3 shows a working machine comprising a terminal 18, the actual machine 19, a camera 31, a microphone 32, a speaker 33 and sensors 34. The camera 19 can preferably be turned in different directions vertically and horizontally. The camera 19 can be any monochrome or colour camera. The microphone 32 and speaker 33 of the terminal 18 allow bi-directional voice transmission. The sensor 34 measures some magnitude significant to the operation of the machine 19, e.g. temperature, and signals the information to the monitoring station 10 to 12 at least in malfunction.

Figure 4 shows a monitoring station. The monitoring station 10 to 12 comprises a monitor 41, displaying the image conveyed by the camera 31 and information on system status presented by the graphic user interface, and working machine control means 42. The monitoring station 10 to 12 also comprises a microphone 43 and a speaker 44 which enable voice transmission.

Let us study the deterministic data transmission protocol of the invention in greater detail by means of the OSI model (Open Systems Interconnection). Deterministic refers to a predetermined data transmission delay irrespective of the load, and is preferably applied only to real-time user information, not to intra-system signalling. The compression of a video image typically takes 120 to 150 ms, a few dozens of milliseconds being left for data transmission when the attempt is to reach a total delay of 150 to 200 ms enabling a substantially real-time remote control. Figure 5 shows a protocol stack comprising a physical layer 51, an I/O layer 52, an MAC layer (Medium Access Control) 53, an I/O routing layer 54 and a control layer 55. Above these is an application layer 56. The physical layer 51 provides the radio interface, the ATM interface and input and output ports for data. The I/O layer 52 provides data packeting, routing of input and output data between pipes 0 to 7, and initialization and control of the hardware. The MAC layer 53 provides connection set-up, automatic identification of adjacent network nodes, transmission of control data in pipe 0, error control, retransmission, etc. The term pipe refers to virtual pipes formed between the units between different input and output ports. The control layer 55 provides connection set-up between the units of the system, automatic identification of the units connected to the system, and transmission and reception of control data between the units by means of the

MAC. Intra-system control data (pipe 0) is routed in the units at the MAC layer 53 and further, if needed, at the control layer 55.

A deterministic protocol is based on five features. All user data, e.g. remote control commands, image information or voice information, is assembled into packets and routed directly at the I/O routing layer to the desired interface (e.g. the radio interface). The terminal or the monitoring station sends the packet at predetermined intervals, e.g. 0.4 ms, and all data received from the I/O (pipes 1 to 7) after the previous packet is included in the packet. The base station routes a packet coming from the terminal via the radio interface directly at the I/O routing layer 54 to the ATM interface towards the monitoring station. The monitoring station or terminal receiving the packet disassembles it and routes the user data directly to the desired I/O port at the I/O routing layer 54 (pipes 1 to 7). No error detection methods or retransmissions are used in user data transmission. Error correction and retransmission can, however, be arranged at the remote control desk of the monitoring station or in the machine to be controlled. The deterministic feature is also facilitated by the network preferably operating as a switched network as does ATM in which data collisions do not occur. The network has a very high capacity and its switches are of non-blocking type.

Pipes, which are always connected to a physical input or output port, are formed between the devices of the data transmission system at the I/O layer 52. The port can be a serial port, a video unit or another device of the data transmission system. On the basis of control information received from the upper layers, the I/O layer 52 recognizes the receiver of the data coming from the different pipes, whereby the data can be immediately forwarded without it having to circulate via the upper layers. Since the terminal and the monitoring station send a packet at regular intervals, the data accumulated from all I/O ports after the previous packet is assembled to the packet. The packet is transferred back to the physical layer either to the radio interface or the ATM interface. At the radio interface, an one-byte preamble, serving to identify and synchronize the packet at the receiver, is inserted at the front of the packet. At the ATM interface, a five-byte field, containing a connection identifier and additional information on connection type, is inserted at the front of the packet. The identifiers inserted by the physical layer are invisible to the I/O layer 52. The base station receives the packets from the ATM network and routes the data from different pipes in a predetermined manner. Control data

(pipe 0) is transferred to the upper layers, and user data (pipes 1 to 7) is transferred directly from the I/O layer 52 to the physical layer at the radio interface. In this way connections are established, the I/O layer 52 is set and the system is controlled at the upper layers. The principle is that the control layer knows the entire transmission system, the MAC layer knows the adjacent nodes, and the I/O layer 52 knows the routing of the data conveyed in the different pipes. All the time, the highest layer in which user data is transferred is the I/O layer 52, ensuring the deterministic data transmission of the invention.

Although the invention has been described above with reference to the example according to the attached drawings, it is obvious that it is not restricted thereto, but can be modified in a variety of ways within the inventive idea disclosed in the attached claims.